NACA

RESEARCH MEMORANDUM

EXPLORATORY INVESTIGATION OF LEADING-EDGE CHORD-EXTENSIONS TO IMPROVE THE LONGITUDINAL STABILITY CHARACTERISTICS OF TWO 52° SWEPTBACK WINGS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Results are presented of exploratory tests obtained with leading-edge wing chord-extensions on two 52° sweptback wings. Both wings exhibit a vortex flow similar to that which has been observed on triangular wings. One wing incorporated circular-arc airfoil sections, and the other wing incorporated NACA 64_1-112 airfoil sections. The aspect ratio was approximately 2.85 for each wing. The tests were conducted at a Reynolds number and Mach number in the vicinity of 6.0×10^6 and 0.12, respectively.

The results constitute preliminary observations and indicate that, on the wing incorporating circular-arc airfoil sections, sharp-nose chord-extensions reduced the aerodynamic-center shift obtained over the entire lift range with the plain wing from 37 to 5 percent of the mean aerodynamic chord. The chord-extensions covered the outer 0.25 semispan and had chords 0.147 of the mean aerodynamic chord. With a reduced chord or span, the stabilizing effectiveness of the chord-extensions was reduced in the vicinity of maximum lift.

The application of round-nose chord-extensions over approximately the outer 0.43 semispan on the wing incorporating NACA 64_1-112 airfoil sections substantially improved the longitudinal stability.

An analysis of the flow would indicate that the diffusion, at the plan-form discontinuity provided by the chord-extensions, of the vortex flow emanating from the wing apex, and for some conditions the formation of a secondary vortex flow over the chord-extensions, was responsible for the improvement in the longitudinal stability of the two wings tested.

The longitudinal stability obtained with chord-extensions was as good as that obtained with extensible leading-edge flaps.

INTRODUCTION

The presence of a vortex type of flow on sweptback wings of certain aspect ratios and thickness ratios can produce large undesirable changes in longitudinal stability at lift coefficients well below maximum lift (reference 1). The vortex flow referred to is similar to that which has been observed on thin or sharp-edge triangular wings and which is qualitatively described in reference 2.

The data presented in references 1, 2, and 3 indicate that the presence of the vortex flow over the tip sections caused an increase in lift at these sections which was responsible for the initial stabilizing aerodynamic-center shift. This initial shift in the aerodynamic center, furthermore, constitutes a large portion of the aerodynamic-center travel over the entire lift range. It was assumed that the elimination or dissipation of this vortex flow over the tip sections would result in an appreciable reduction in the over-all aerodynamic-center travel. Some reduction was obtained in the tests reported in reference 1 through the application of extensible leading-edge flaps. Subsequent tests on the same wing indicated that the greatest reduction in aerodynamic-center travel that could be obtained was critically dependent on the spanwise location of the plan-form discontinuity that occurred at the inboard end of the leading-edge flaps. The dependence of the improvement in stability on the plan-form discontinuity suggested the possibility that small-span chord-extensions could provide the discontinuity necessary to upset the effect of the vortex flow. Such a device could be extended when required, or if the high-speed characteristics proved satisfactory, it could be fixed. In either case, the chord-extensions would appear to be less complicated than the stall-control devices currently being used on sweptback wings which exhibit the vortex flow.

The present paper presents the results of exploratory tests obtained with outboard wing chord-extensions on two 52° sweptback wings which exhibit the vortex flow. A comparison is made of the effects of extensible leading-edge flaps with the effects of the chord-extensions on the lift, drag, and pitching-moment characteristics of each wing. One wing incorporated circular-arc airfoil sections, and the other wing incorporated NACA 64_1-112 airfoil sections. The aspect ratio was approximately 2.85 for each wing.

The term "chord-extension" is used herein to designate a device which extends the normal wing chord over an outboard portion of the leading edge. The purpose of this device is to improve the longitudinal stability characteristics of sweptback wings which exhibit a vortex flow lying on the upper surface.

SYMBOLS

C_L	lift coefficient $\left(\frac{\text{Lift}}{qS}\right)$
C_D	drag coefficient $\left(\frac{\text{Drag}}{qS}\right)$
C_m	pitching-moment coefficient about $0.25\bar{c}$ $\left(\frac{\text{Pitching moment}}{qS\bar{c}}\right)$
x_{ac}	approximate aerodynamic-center location, percent $\bar{c}$ $\left(0.25 - \frac{dC_m}{dC_L}\right)100$
α	angle of attack, degrees
R	Reynolds number
q	stream dynamic pressure, pounds per square foot
M	Mach number
S	wing area (basic wing)
b	wing span
$\bar{c}$	mean aerodynamic chord $\left(\frac{2}{S}\int_0^{b/2} c^2 dy\right)$
A	aspect ratio
λ	taper ratio
c	local chord
y	spanwise ordinate
$\frac{dC_m}{dC_L}$	rate of change of pitching-moment coefficient with lift coefficient

[redacted]

MODELS, TESTS, AND CORRECTIONS

Model.- The model plan forms, together with pertinent geometric dimensions, are shown in figure 1. Neither model had dihedral or twist. The wing incorporating symmetrical circular-arc airfoil sections normal to the 0.50-chord line (line of maximum thickness) had a 9.8-percent-chord thickness at the root and a 6.1-percent-chord thickness at the tip. The other wing incorporated NACA 64_1-112 airfoil sections normal to the 0.282-chord line.

The extensible leading-edge flaps and wing chord-extensions tested on each wing model are shown in figure 2.

The 52° sweptback wing having an aspect ratio of 2.84 and incorporating circular-arc airfoil sections is referred to as the "circular-arc" wing, and the 52° sweptback wing having an aspect ratio of 2.88 and incorporating NACA 64_1-112 airfoil sections is referred to as the "64-series" wing.

The 64-series wing is shown mounted on the two-support system of the Langley 19-foot pressure tunnel in figure 3.

Tests.- The tests were conducted in the Langley 19-foot pressure tunnel with the air compressed to an absolute pressure of 33 pounds per square inch.

Data were obtained on the circular-arc wing and 64-series wing at the conditions listed in the following table:

Configuration		R	M	q (lb/sq ft)
Circular-arc wing	Plain wing	6.0×10^6	0.12	46
	All others	5.5	.11	40
64-series wing	Plain wing	6.0	.12	46
	All others	6.0	.12	46

The Reynolds numbers were based on the respective mean aerodynamic chords.

Lift, drag, and pitching-moment data were obtained through an angle-of-attack range from approximately -4° to an angle beyond maximum lift.

Corrections.- The lift, drag, and pitching moment have been corrected for support tare and strut interference as determined by tare tests. The angles of attack and drag data have been corrected for jet-boundary effects by the method presented in reference 4. The pitching-moment data have been corrected for jet-boundary effects by an extension of the method presented in reference 4. In addition, the angles of attack have been corrected for air-stream misalinement.

RESULTS AND DISCUSSION

Force Characteristics

The lift, drag, and pitching-moment characteristics obtained for the circular-arc wing equipped with chord-extensions of various spans and chords and an extensible leading-edge flap are presented in figures 4 to 7. Similar data are presented for the 64-series wing in figures 8 to 11. Comparisons of the longitudinal stability obtained with these devices have been made in figures 12 and 13 where variations of instantaneous aerodynamic center are plotted against lift coefficient for the circular-arc and 64-series wing, respectively. The values of aerodynamic center in the high-lift range are of an approximate nature, inasmuch as the drag has not been taken into account in the calculations.

In the present investigation the inboard-end locations of the chord-extensions were selected on the basis of more extensive tests (unpublished data) with extensible leading-edge flaps.

Circular-arc wing.- The plain wing exhibited large undesirable shifts in aerodynamic center throughout the lift range. The shift of the aerodynamic center from its most forward to most rearward position between zero and maximum lift amounted to 37 percent of the mean aerodynamic chord (figs. 4 and 12(a)). Outboard chord-extensions having 6-inch chords (14.7 percent $\bar{c}$) and located over approximately the outer 25 percent of the semispan reduced the aerodynamic-center travel of the plain wing to a 5-percent mean-aerodynamic-chord shift between zero and maximum lift (figs. 4 and 12(a)). The spans of the 6-inch chord-extensions were reduced to 0.13 and 0.06 of the semispan while the inboard ends of the chord-extensions were fixed at the same spanwise position. The pitching-moment characteristics obtained with the 6-inch chord-extensions of reduced spans are presented in figure 4. The variations in aerodynamic center with lift coefficient obtained with the chord-extensions of reduced span (fig. 12(a)) indicate increases in aerodynamic-center travel in the high-lift range over that obtained with 0.25b/2 chord-extensions. In both cases, however, the reduced-span chord-extensions eliminated the initial aerodynamic-center shift and hence materially reduced the over-all aerodynamic-center travel of the plain wing. With the chord of the chord-extensions reduced to 3 inches (7.4 percent $\bar{c}$), the aerodynamic-center travel was comparable to that obtained with the 6-inch chord-extensions of reduced spans; that is, the initial aerodynamic-center shift was eliminated but measurable shifts occurred in the high-lift range (fig. 12(b)). Reductions in the spans of the 3-inch chord-extensions allowed aerodynamic-center shifts in the high-lift range which may be considered objectionable (figs. 6 and 12(c)).

The application of chord-extensions had, in general, a straightening effect on the lift curves (figs. 4 to 7). It is interesting to note that small increases in maximum lift were obtained that were somewhat greater than the increase in area provided by the chord-extensions.

The drag data (figs. 4 to 7) indicate that chord-extensions had practically a negligible effect on the drag throughout the lift range although a slight decrease is obtained in the maximum-lift range.

The data presented in figures 6 and 11(d) indicate that chord-extensions are as effective in reducing the aerodynamic-center travel of the plain wing as the extensible leading-edge flaps. The extensible leading-edge flaps, it should be pointed out, caused an increase in drag over most of the lift range.

<u>64-series wing</u>.- The shift of the aerodynamic center from its most forward to most rearward position between zero and maximum lift for the plain wing amounted to an 87-percent mean-aerodynamic-chord travel (figs. 9 and 13(a)). Outboard chord-extensions having 6-inch chords (similar to those used on the circular-arc wing) and located over approximately the outer 0.43 percent of the semispan reduced the large aerodynamic-center travel of the plain wing appreciable between zero and maximum lift (figs. 9 and 13(a)). To indicate the effect of the nose shape of the chord-extensions on a wing having subsonic airfoil sections, tests were also made with round-nose chord-extension (fig. 2). The results obtained (figs. 8, 9, 13(a), and 13(b)) indicate that the initial aerodynamic-center shift is delayed to a higher lift coefficient and the magnitude of the shift is reduced with either the round- or sharp-nose chord-extensions. The data do indicate, however, that the round-nose chord-extensions are superior to the sharp-nose chord-extensions in regard to longitudinal stability, maximum lift, and drag.

The results obtained on the 64-series wing, even with round-nose chord-extensions, are not so favorable as those obtained with chord-extensions on the circular-arc wing. This fact is especially true from considerations of the increase in drag in the moderate-lift range and to some extent the longitudinal stability just at maximum lift. The increase in drag was greatly reduced by using round-nose rather than sharp-nose chord-extensions on the 64-series wing. Inasmuch as the round nose used in these tests was arbitrarily selected, the possibility exists that it is not the optimum nose shape.

The effects of variations in length of chord and span of the chord-extensions are similar to those obtained on the circular-arc wing (figs. 8, 9, 10, and 13(c)).

The 6-inch round-nose chord-extensions provide a greater stabilizing effect than the extensible leading-edge flaps. The 3-inch round-nose chord-extensions were about equally as stabilizing as the extensible leading-edge flaps.

Flow Characteristics

Although pressure-distribution tests would be required to explain fully the action of the chord-extensions, some comments can be made on the basis of tuft probing and the force data obtained.

Visual flow observations, by means of a tuft attached to a wooden probe, indicated that the vortex flow lies along the leading edge from the wing apex to the plan-form discontinuity. Although the probe observations then became indefinite, it appeared that the vortex flow trailed off the wing at this station. It was observed that in the case of the sharp-nose chord-extensions a secondary vortex formed over the chord-extensions. No tuft observations were made on the 64-series wing with the round-nose chord-extensions.

The elimination of the initial aerodynamic-center shifts which occurred on the plain wings when the vortex flow formed, by even the smallest-chord and smallest-span chord-extensions, indicate that the discontinuity in plan form evidently diffused the vortex flow emanating from the wing apex in such a way as to prevent any additional lift over the tip sections.

The strength of the secondary vortex which forms over the chord-extensions is dependent on the span of the chord-extensions and angle of attack. This fact is indicated by the force data where the large-span chord-extensions provided slightly more negative pitching moment near maximum lift than the shorter-span chord-extensions and, hence, were slightly more effective in reducing the aerodynamic-center travel of the wings. In addition, the secondary vortex probably accounts for the increase in maximum lift not accounted for by the area increase.

In both cases the addition of chord-extensions produced straighter lift curves although not in the same manner. In the case of the circular-arc wing, chord-extensions caused reductions in lift coefficient in the moderate-lift range that can be attributed to the prevention of the increases in lift over the tip sections which normally occur when the vortex flow is formed. In the case of the plain 64-series wing, the inflection in the lift curve is rather abrupt and occurs at a moderately high angle of attack. The lift curve is straightened with chord-extensions by an increase in lift throughout the low- and moderate-lift range, and this additional lift is due to the increase in wing area in the case of the round-nose chord-extensions and to the increase in area and secondary vortex in the case of the sharp-nose chord-extensions (fig. 9).

The drag due to the chord-extensions on the circular-arc wing was negligible. The increase to be expected from the increased wing area was probably compensated for by the diffusion of the vortex flow emanating from the wing apex. In the case of the 64-series wing, the sharp-nose chord-extensions formed a vortex flow at much lower angles of attack than the one at which it normally occurred on the plain wing and, hence, caused a drag increase in addition to that obtained with the increase in wing area. The increase in drag due to the round-nose chord-extensions was much less because of the fact that a secondary vortex flow is not precipitated.

The results obtained on the circular-arc and 64-series wings indicate that altering the effects of the vortex flow by means of chord-extensions extending over approximately the outer 25-percent and 43-percent semispan, respectively, produced satisfactory longitudinal stability. Thus, two wings having the same sweep angle and aspect ratio require greatly different spans of chord-extension, which is attributed to the fact that the formation, strength, and position of the vortex flow is, among other things, dependent on leading-edge radius. The two wings considered here differ greatly in this respect.

CONCLUDING REMARKS

The results obtained with leading-edge wing chord-extensions on two 52° sweptback wings which have aspect ratios of approximately 2.85 indicate that:

On the wing incorporating circular-arc airfoil sections, sharp-nose chord-extensions reduced the aerodynamic-center shift obtained over the entire lift range with the plain wing from 37 to 5 percent of the mean aerodynamic chord. The chord-extensions covered the outer 0.25 semispan and had chords 0.147 of the mean aerodynamic chord. With a reduced chord or span, the stabilizing effectiveness of the chord-extensions was reduced in the vicinity of maximum lift.

The application of round-nose chord-extensions over approximately the outer 0.43 semispan on the wing incorporating NACA 64_1-112 airfoil sections substantially improved the longitudinal stability.

An analysis of the flow would indicate that the diffusion, at the plan-form discontinuity provided by the chord-extensions, of the vortex flow emanating from the wing apex, and for some conditions the formation of a secondary vortex flow over the chord-extensions, was responsible for the improvement in longitudinal stability of the two wings tested.

The longitudinal stability obtained with chord-extensions was as good as that obtained with extensible leading-edge flaps.

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2. Wilson, Herbert A., Jr., and Lovell, J. Calvin: Full-Scale Investigation of the Maximum Lift and Flow Characteristics of an Airplane Having Approximately Triangular Plan Form. NACA RM L6K20, 1947.

3. Lange, Roy H., Whittle, Edward F., Jr., and Fink, Marvin P.: Investigation at Large Scale of the Pressure Distribution and Flow Phenomena over a Wing with the Leading Edge Swept Back 47.5° Having Circular-Arc Airfoil Sections and Equipped with Drooped-Nose and Plain Flaps. NACA RM L9G15, 1949.

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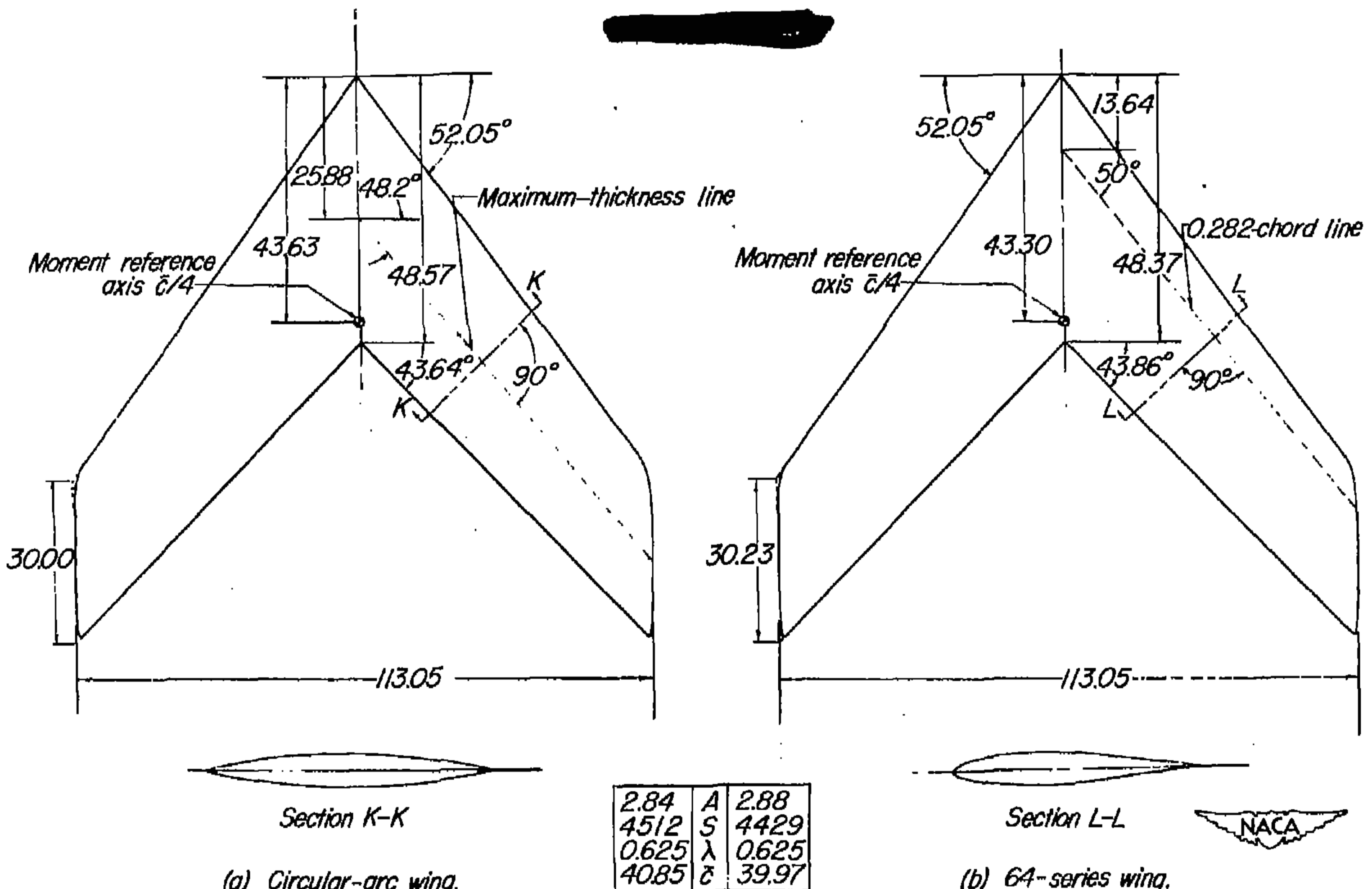

2.84	A	2.88
4512	S	4429
0.625	λ	0.625
40.85	$\bar{c}$	39.97

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Figure 1.- Geometry of 52° sweptback wings having circular-arc and NACA 64_1-112 airfoil sections. All dimensions are in inches.

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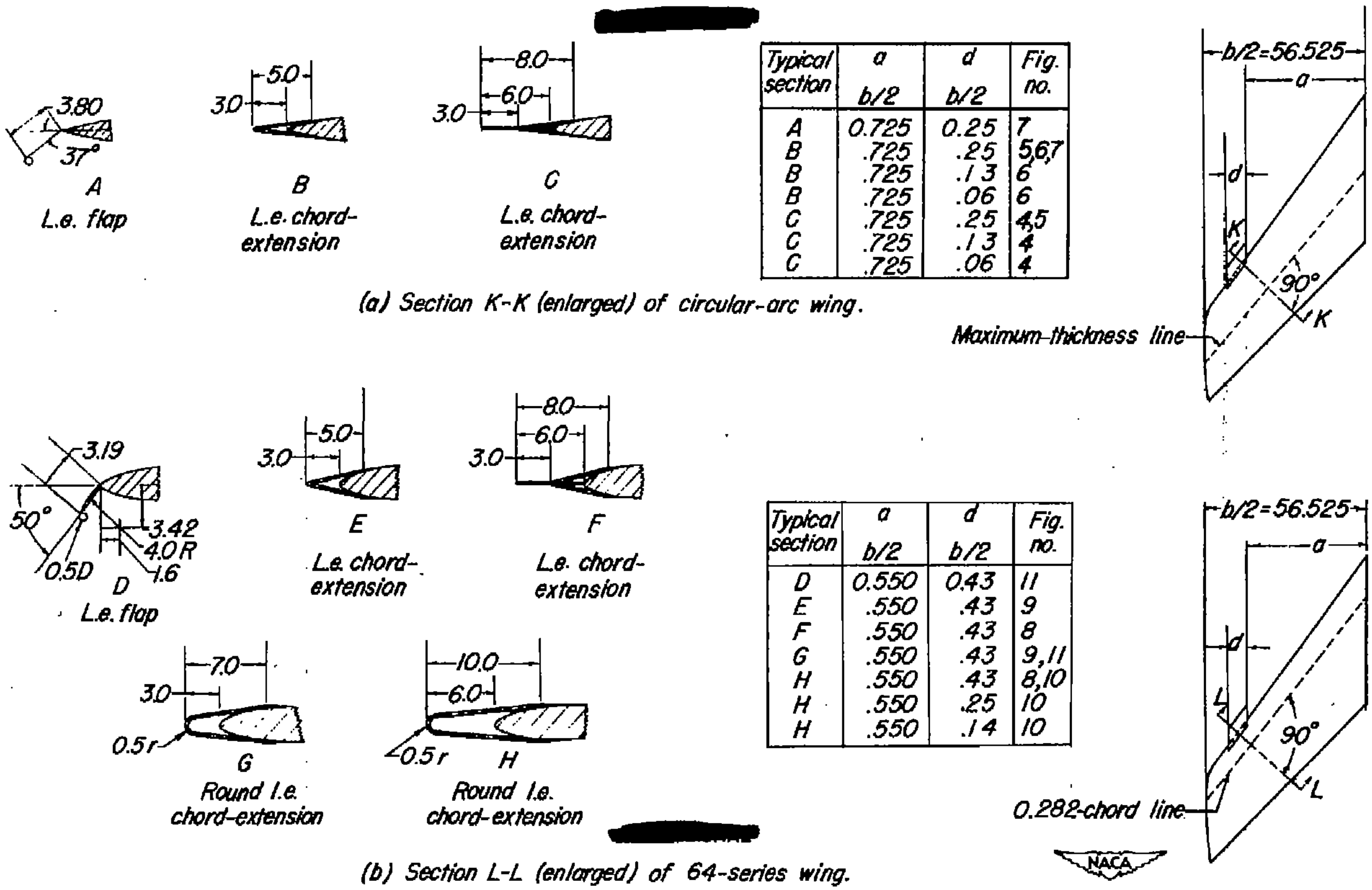

Typical section	a / b/2	d / b/2	Fig. no.
A	0.725	0.25	7
B	.725	.25	5,6,7
B	.725	.13	6
B	.725	.06	6
C	.725	.25	4,5
C	.725	.13	4
C	.725	.06	4

(a) Section K-K (enlarged) of circular-arc wing.

Typical section	a / b/2	d / b/2	Fig. no.
D	0.550	0.43	11
E	.550	.43	9
F	.550	.43	8
G	.550	.43	9,11
H	.550	.43	8,10
H	.550	.25	10
H	.550	.14	10

[redacted]

(b) Section L-L (enlarged) of 64-series wing.

Figure 2.- Details of typical leading-edge devices for circular-arc and 64-series wings. All dimensions are in inches unless otherwise specified.

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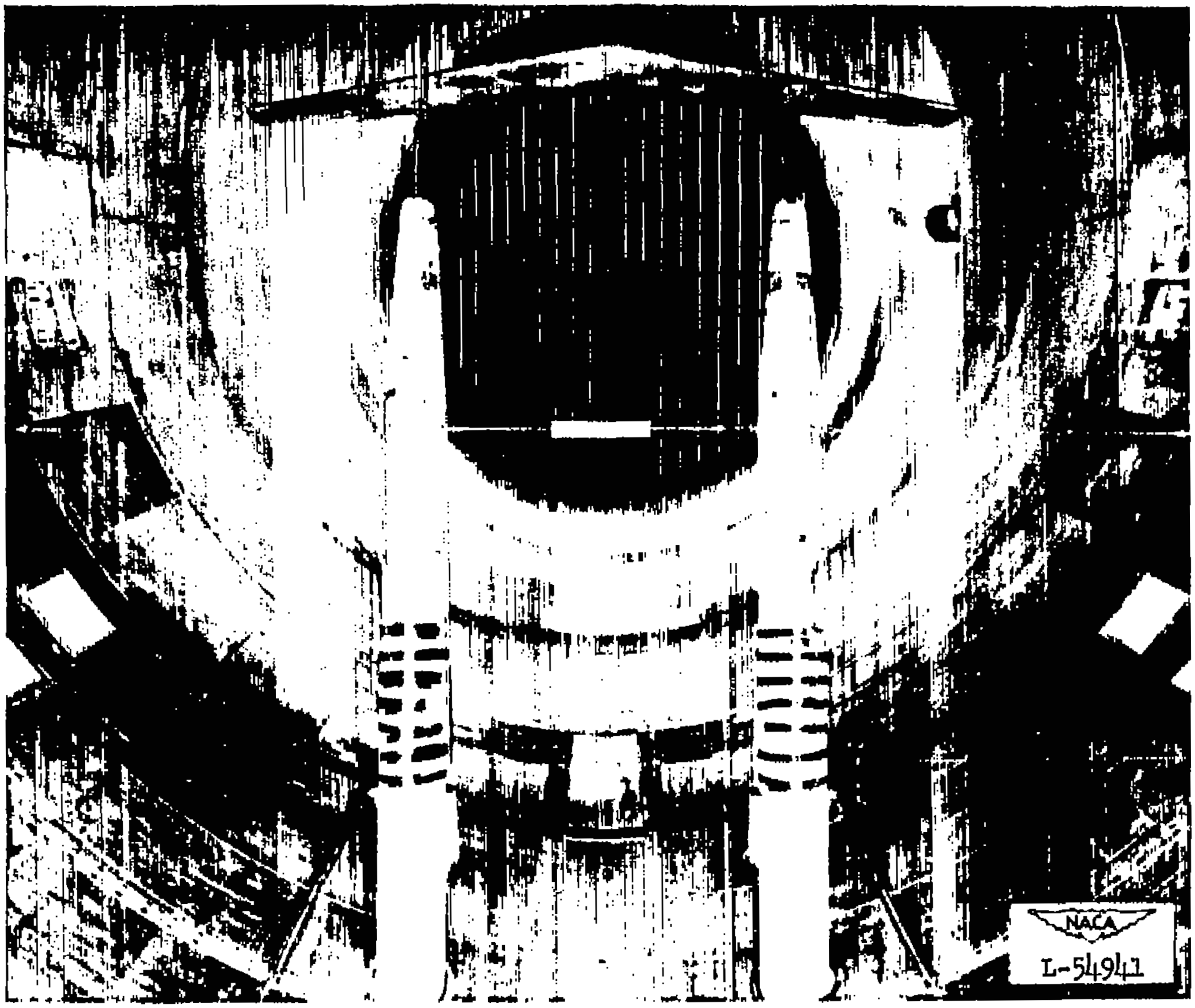

Figure 3.- NACA 64-series 52° sweptback wing mounted in the Langley 19-foot pressure tunnel.

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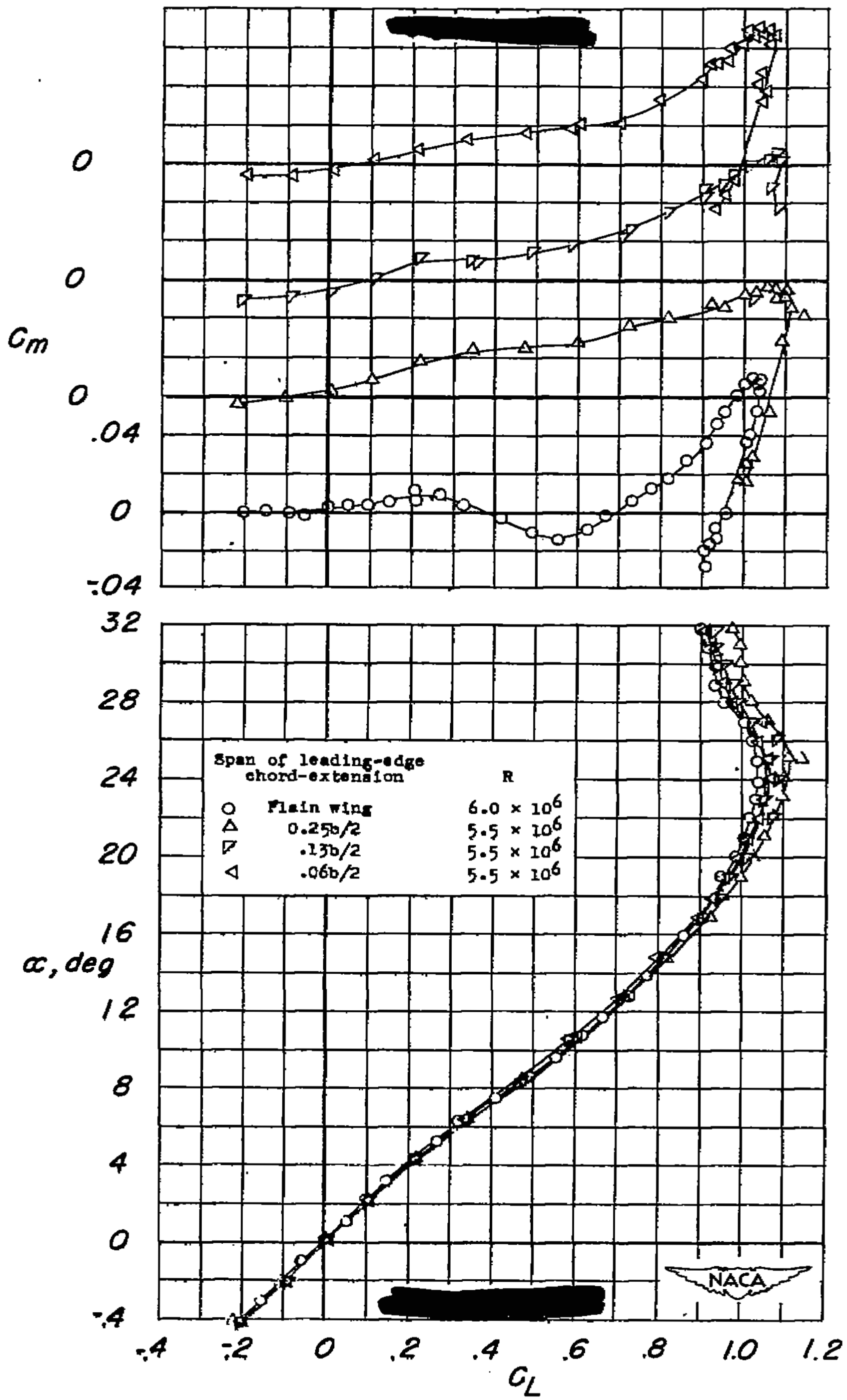

Figure 4.- The effect of a 6-inch leading-edge chord-extension of several spans on the aerodynamic characteristics of a 52° sweptback circular-arc wing.

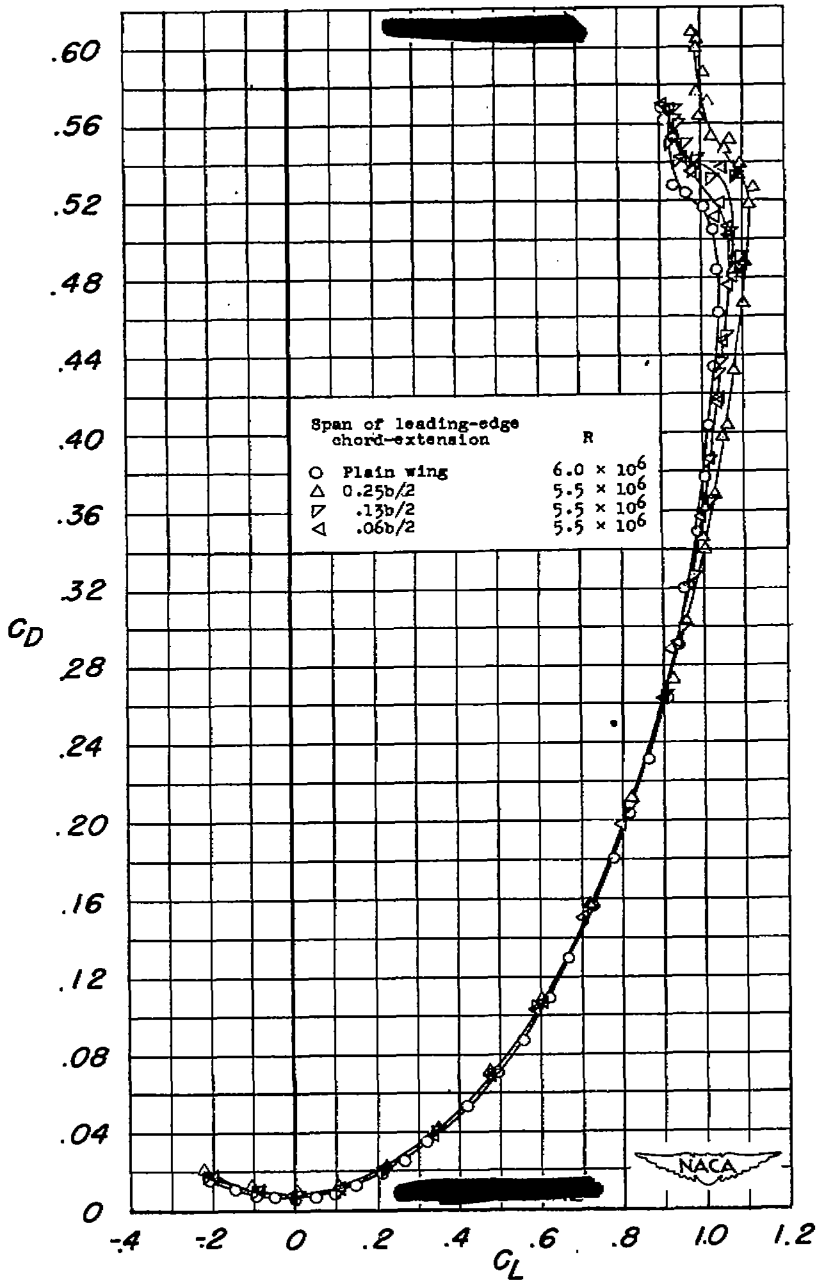

Figure 4.- Concluded.

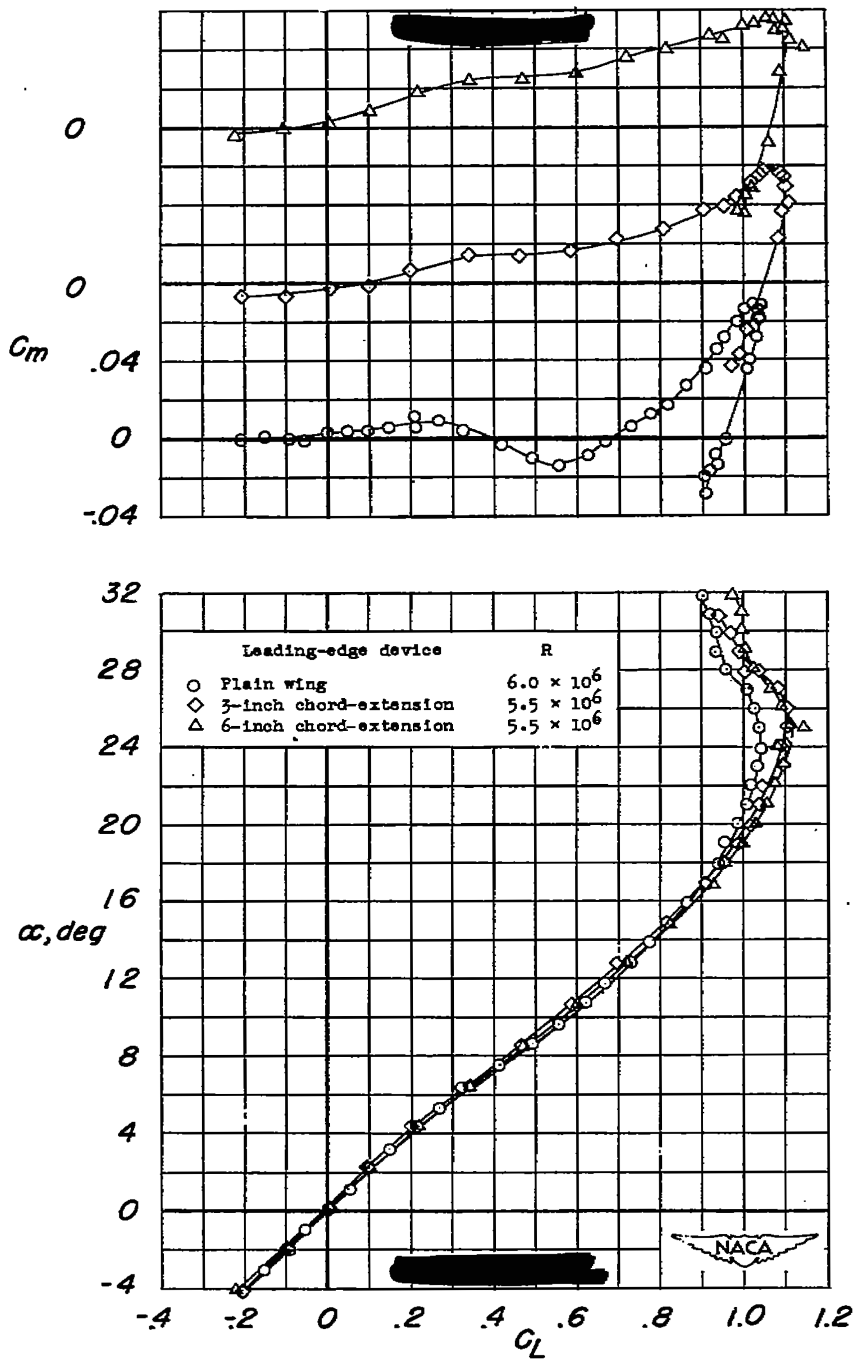

Figure 5.- The effect of a 3-inch and 6-inch leading-edge chord-extension on the aerodynamic characteristics of a 52° sweptback circular-arc wing; 0.25b/2 span.

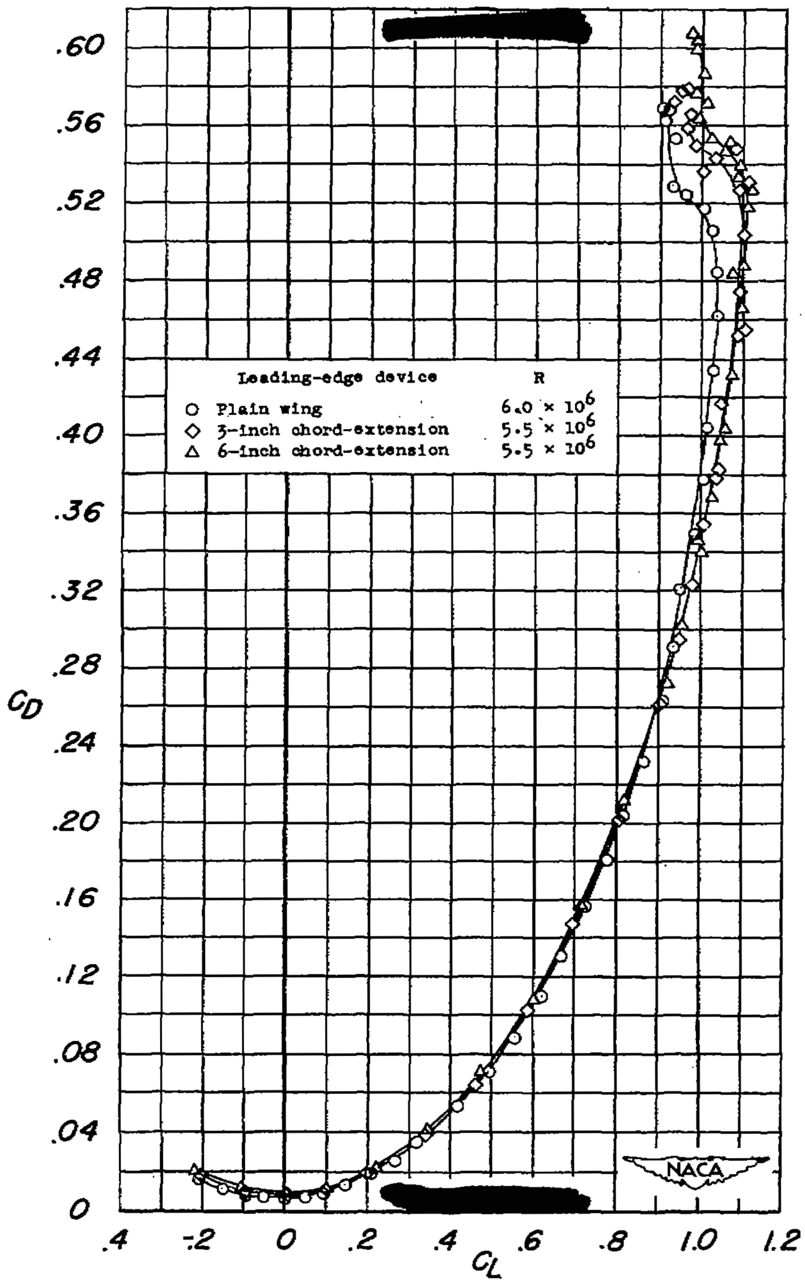

Figure 5.- Concluded.

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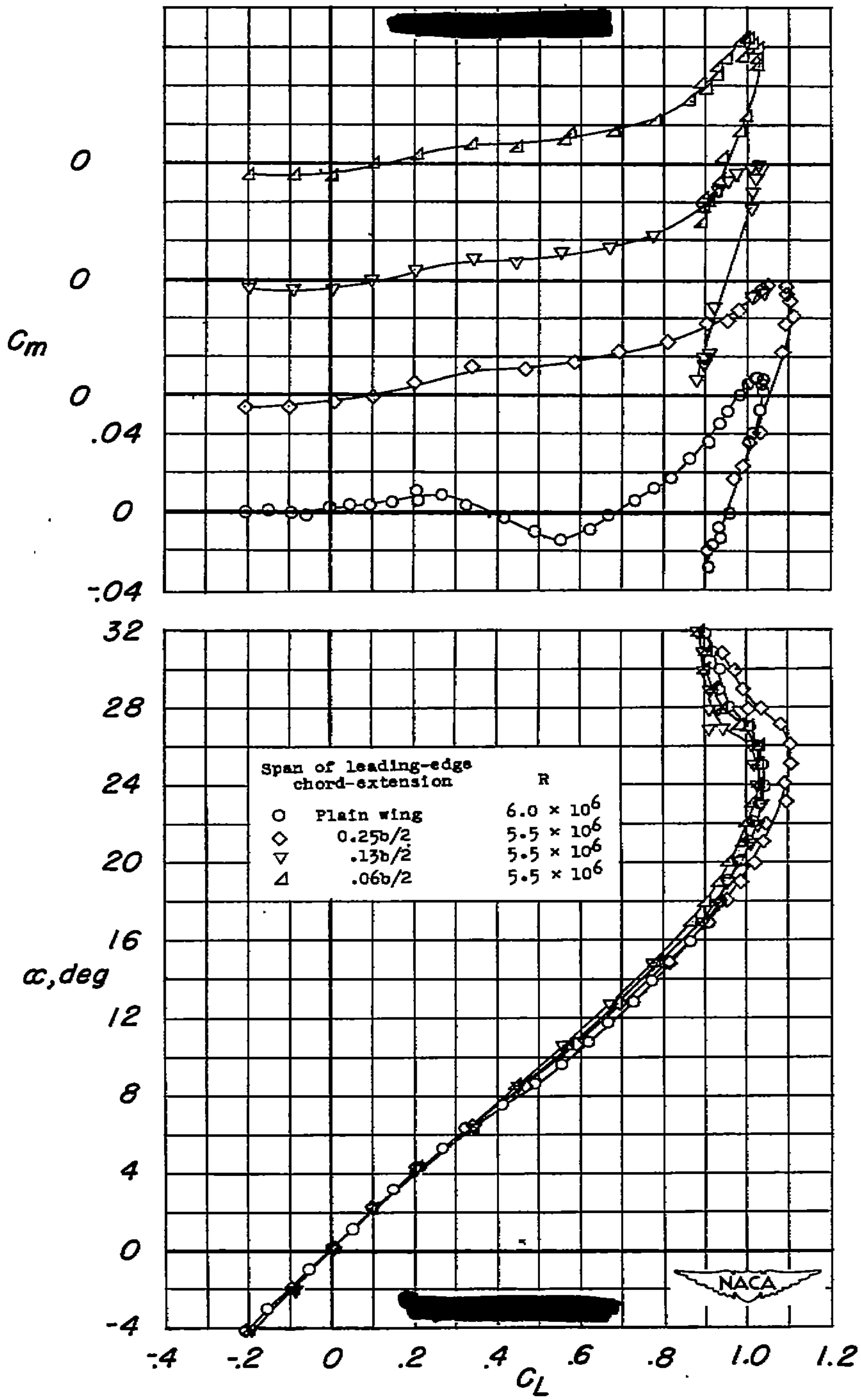

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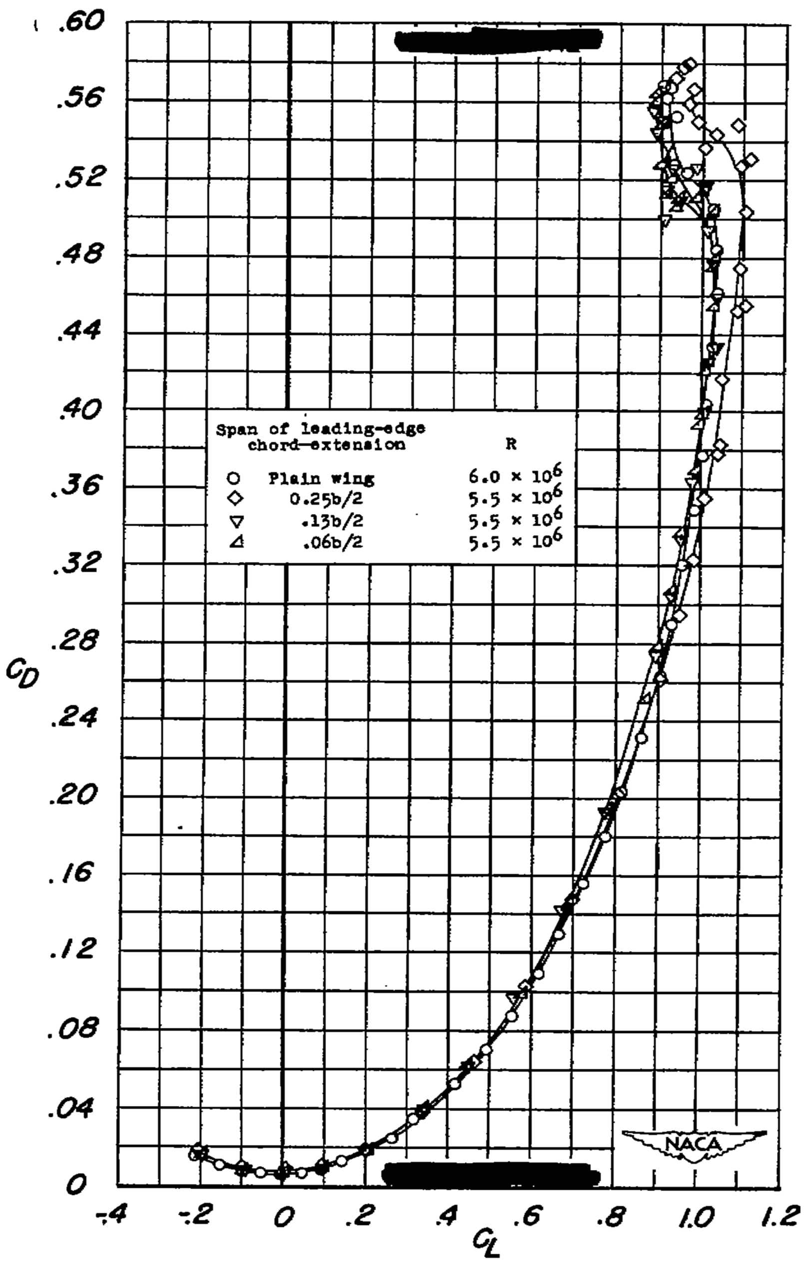
Figure 6.- The effect of a 3-inch leading-edge chord-extension of several spans on the aerodynamic characteristics of a 52° sweptback circular-arc wing.



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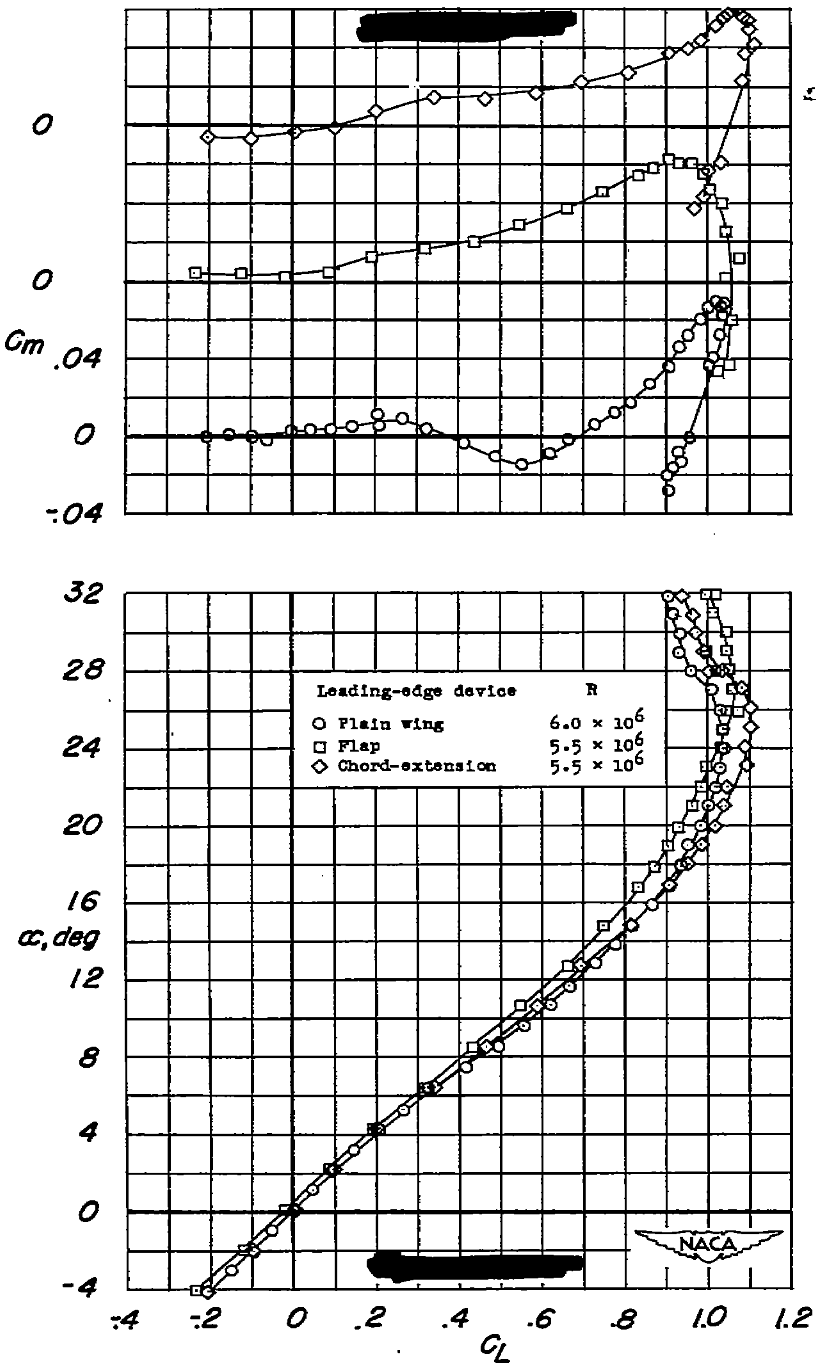

Figure 7.- A comparison of the effects of leading-edge flaps and 3-inch leading-edge chord-extensions on the aerodynamic characteristics of a 52° sweptback circular-arc wing; 0.25b/2 span.

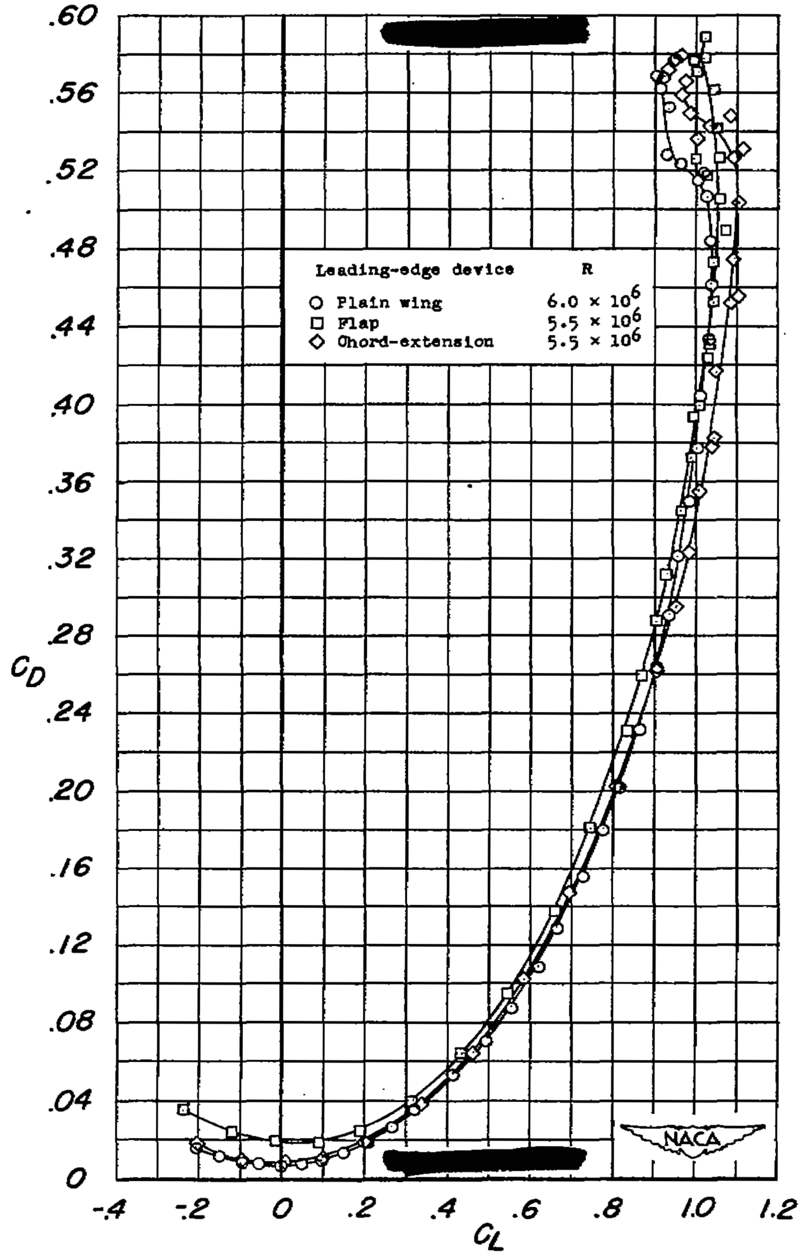

Figure 7.- Concluded.

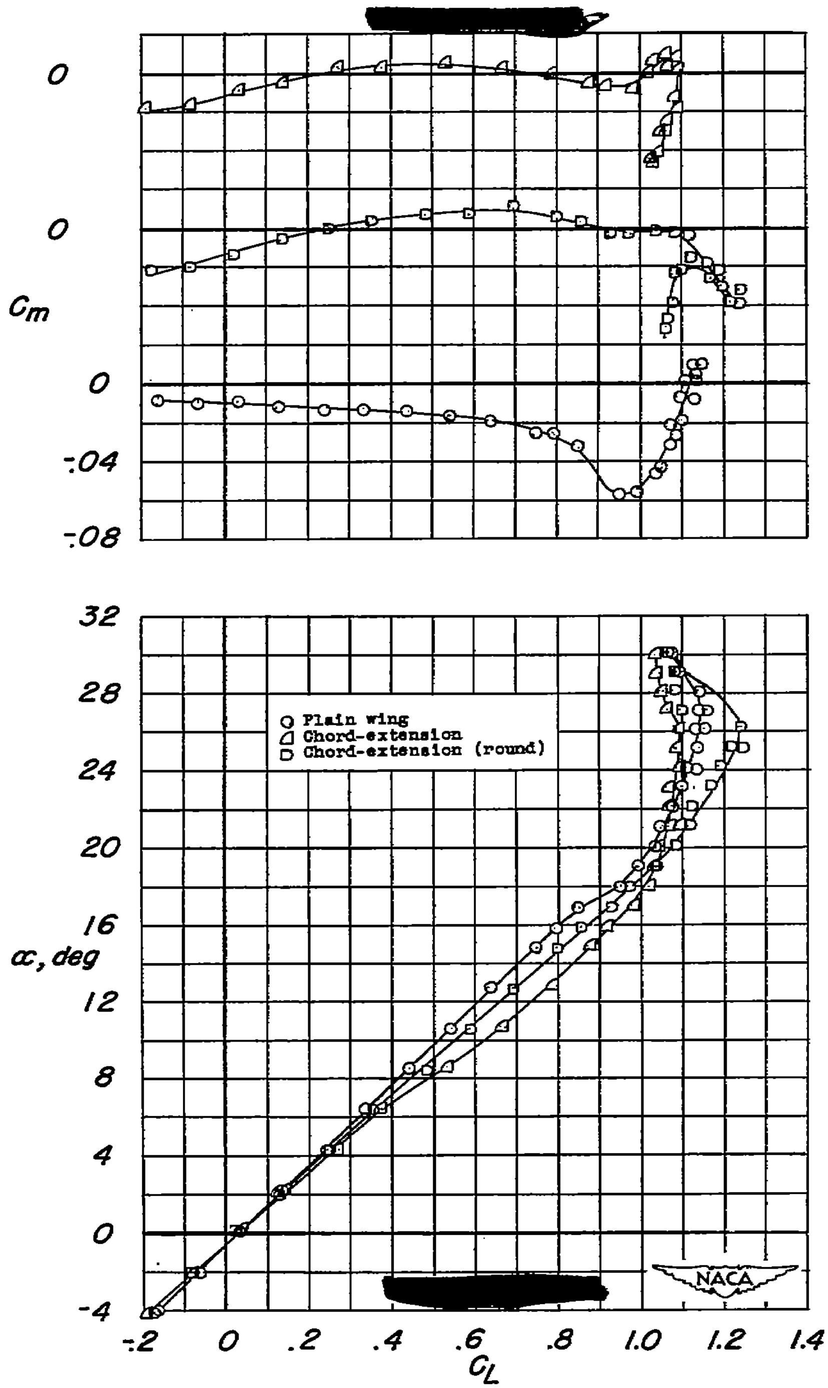

Figure 8.- The effect of a round and sharp 6-inch leading-edge chord-extension on the aerodynamic characteristics of an NACA 64-series 52° sweptback wing; 0.43b/2 span; R = 6,000,000.

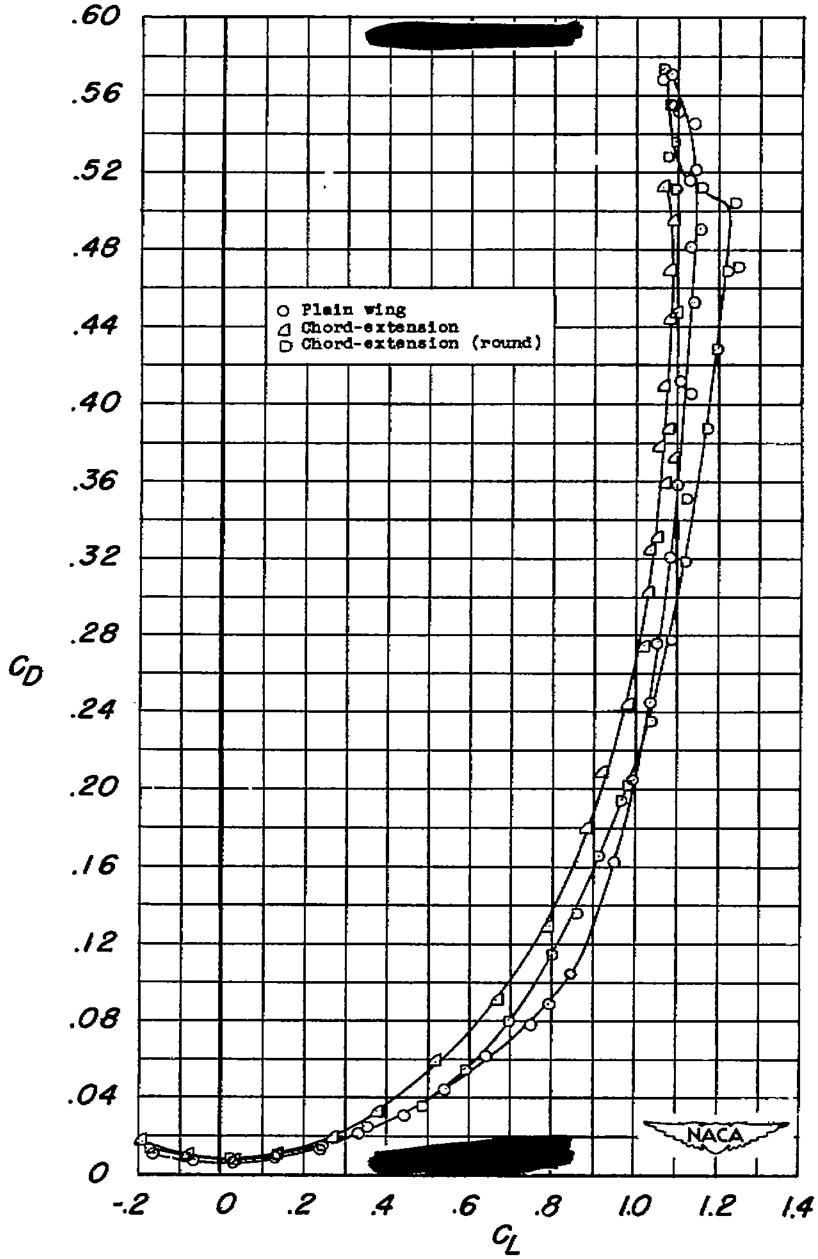

Figure 8.- Concluded.

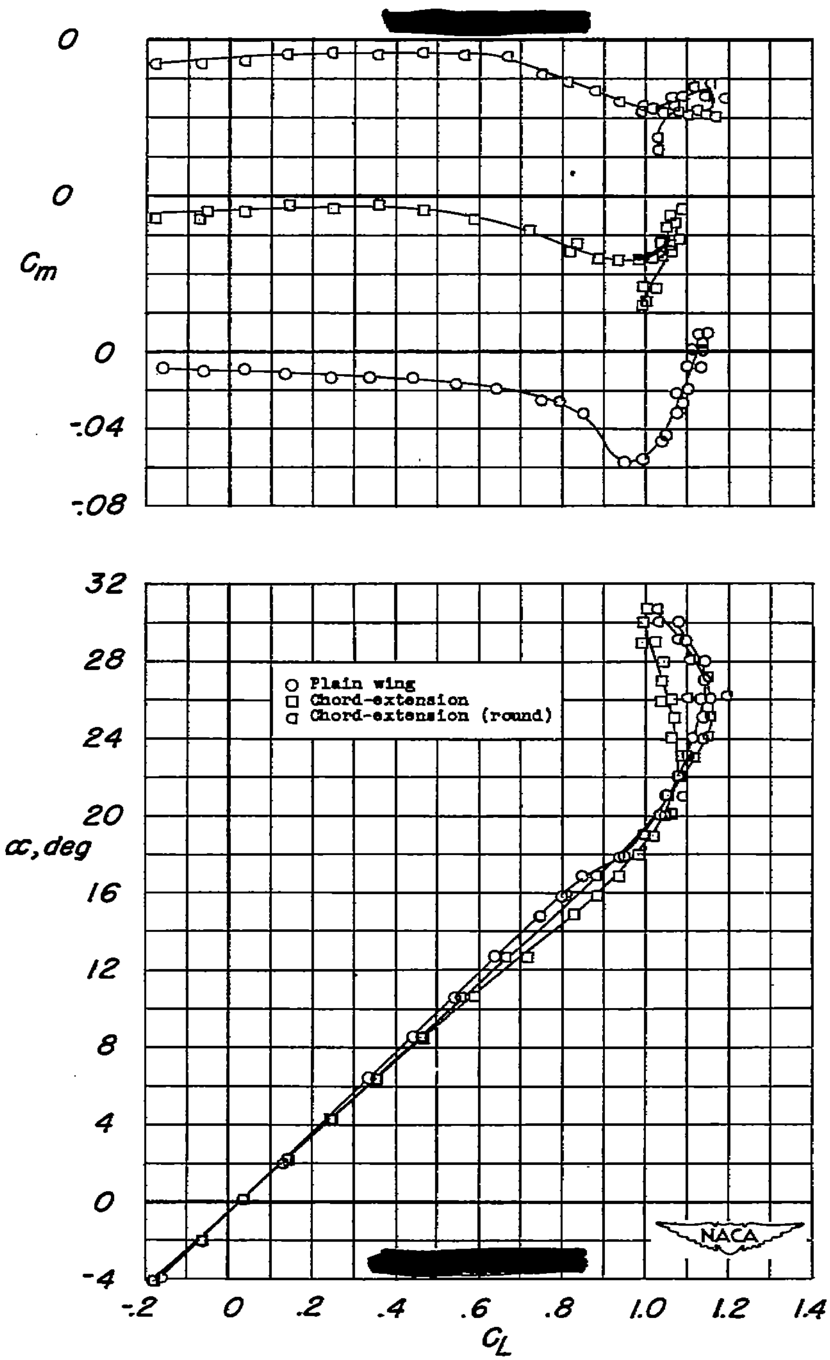

Figure 9.- The effect of a round and sharp 3-inch leading-edge chord-extension on the aerodynamic characteristics of an NACA 64-series 52° sweptback wing; 0.43b/2 span; R = 6,000,000.

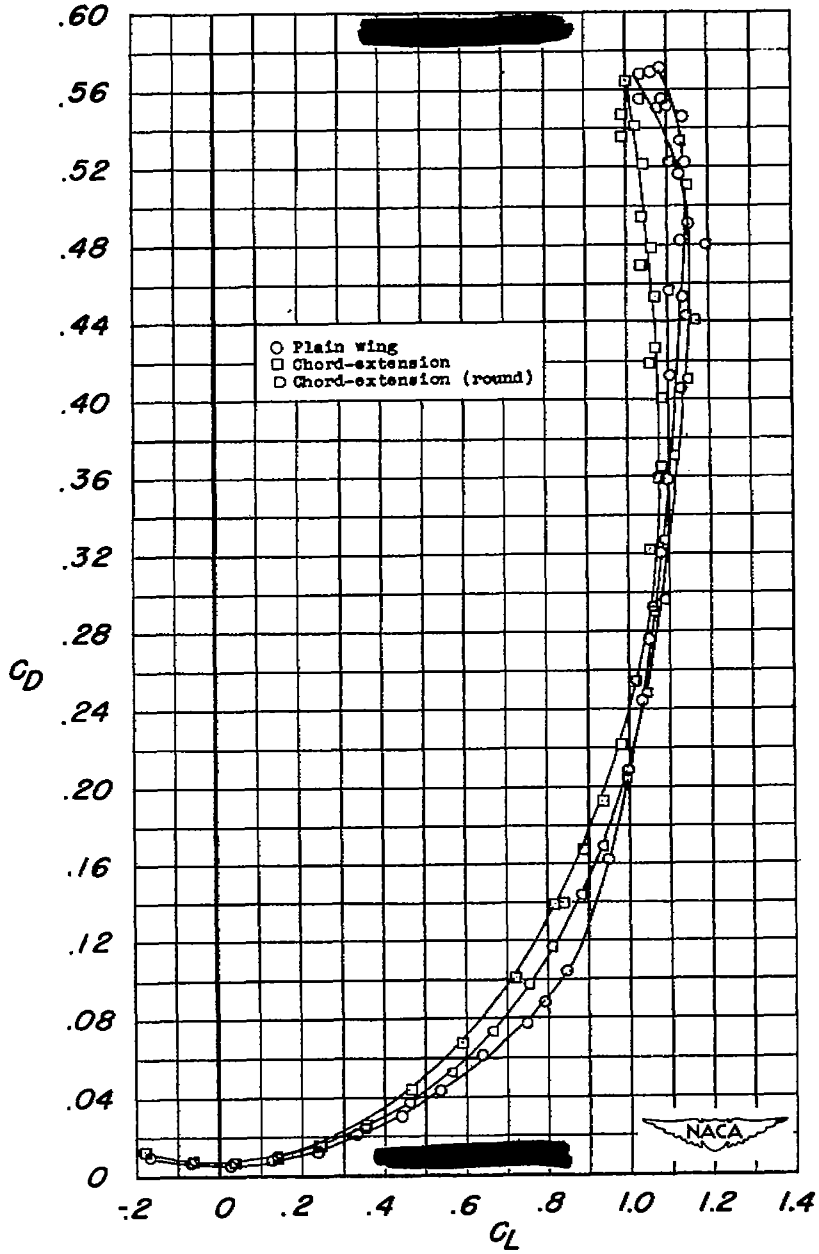

Figure 9.- Concluded.

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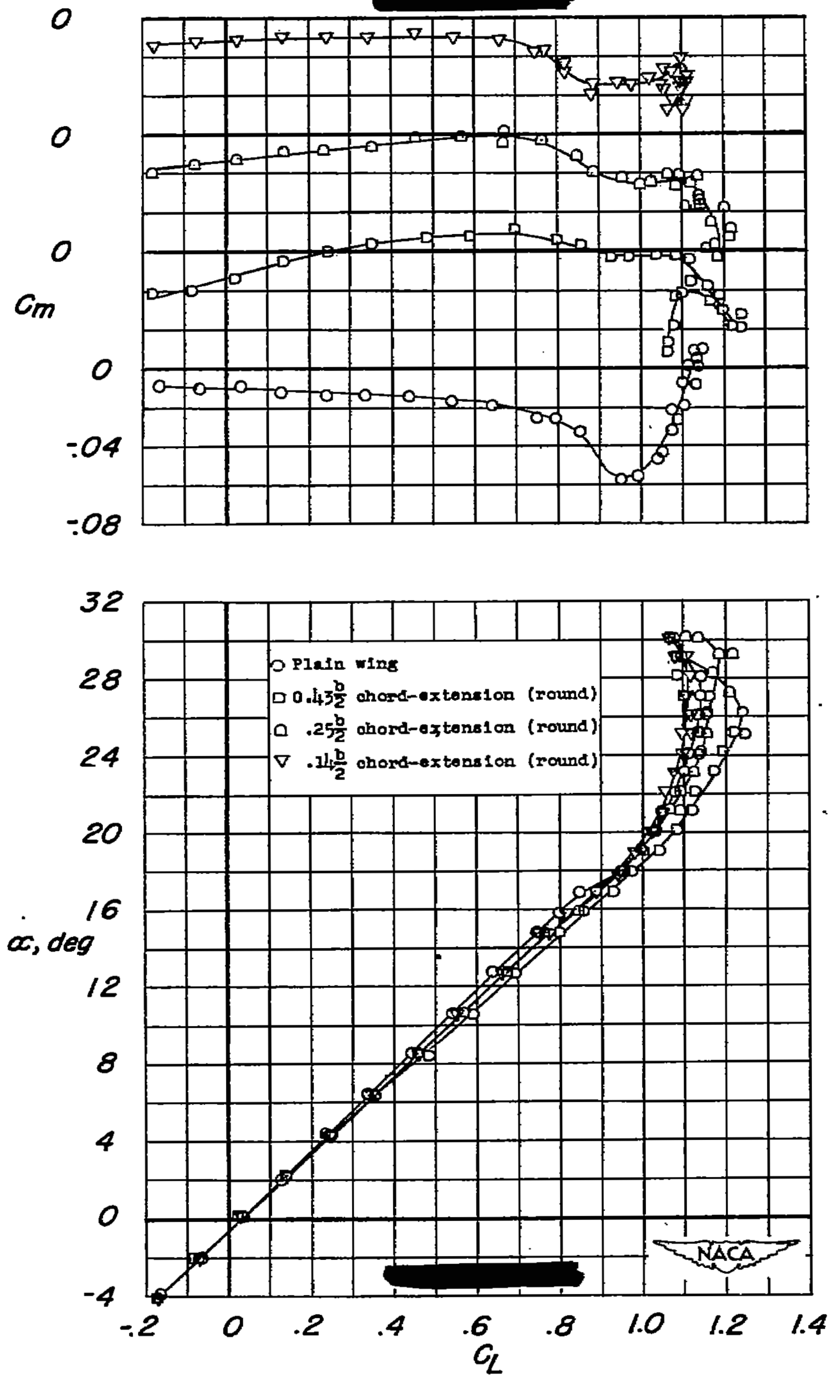

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Figure 10.- The effect of a round 6-inch leading-edge chord-extension of several spans on the aerodynamic characteristics of an NACA 64-series 52° sweptback wing; R = 6,000,000.

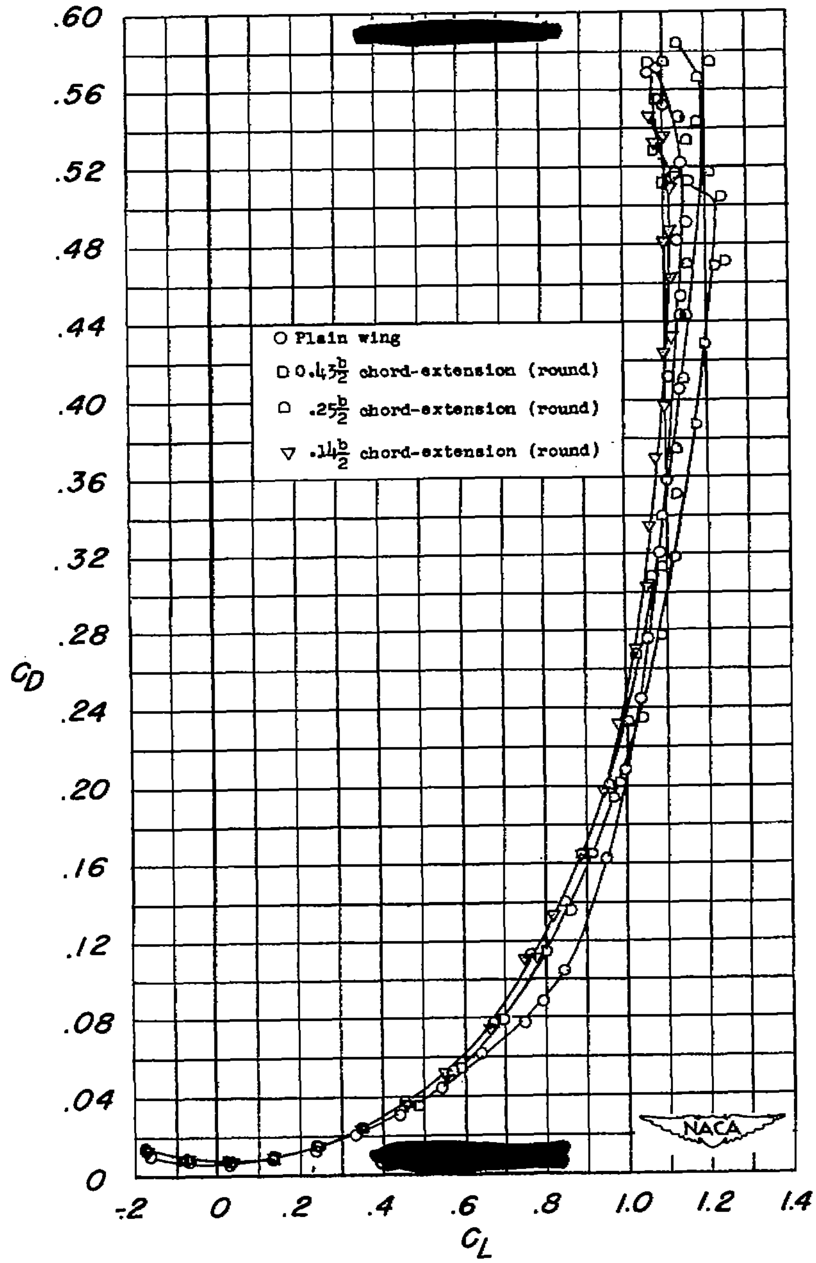

Figure 10.- Concluded.

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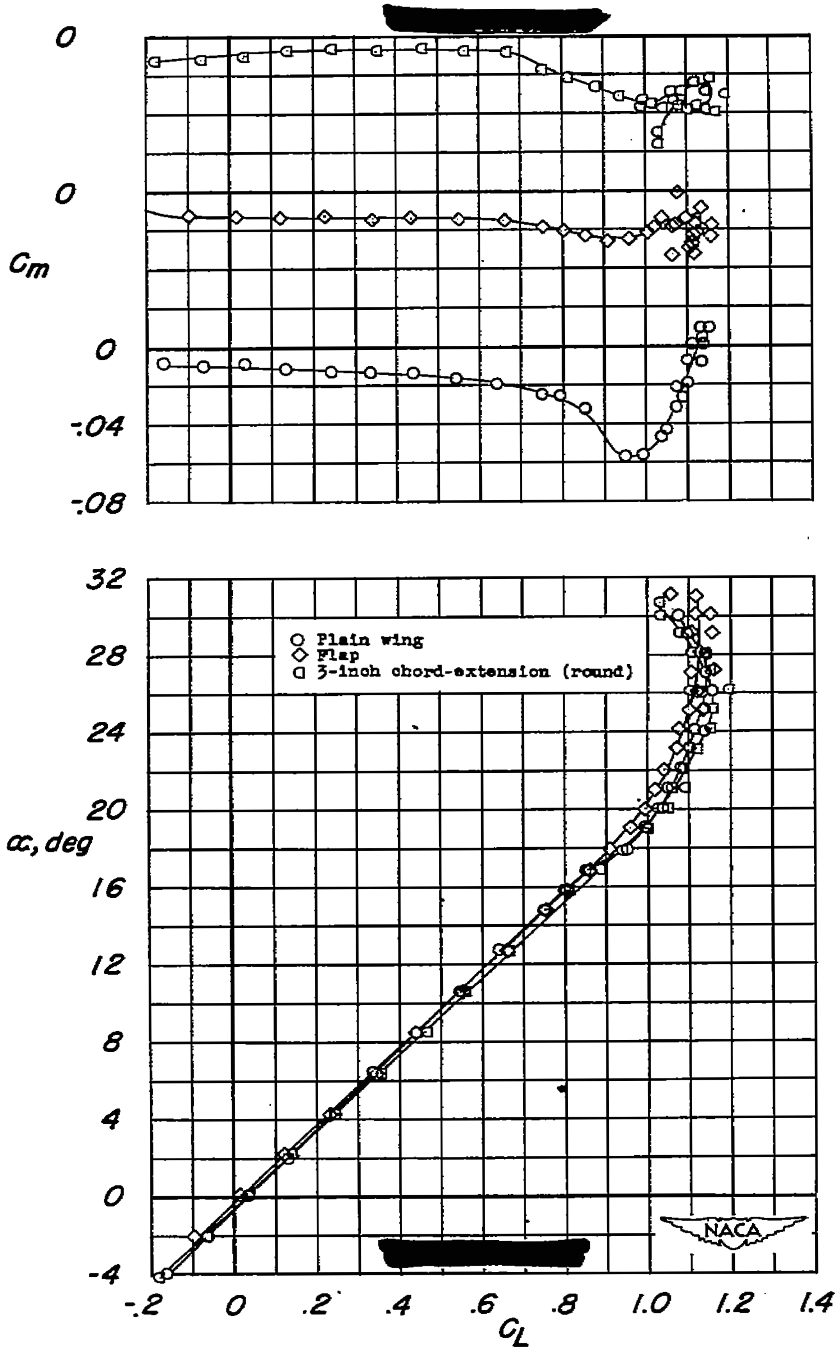

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Figure 11.- A comparison of the effects of leading-edge flaps and round 3-inch leading-edge chord-extension on the aerodynamic characteristics of an NACA 64-series 52° sweptback wing; 0.43b/2 span; R = 6,000,000.

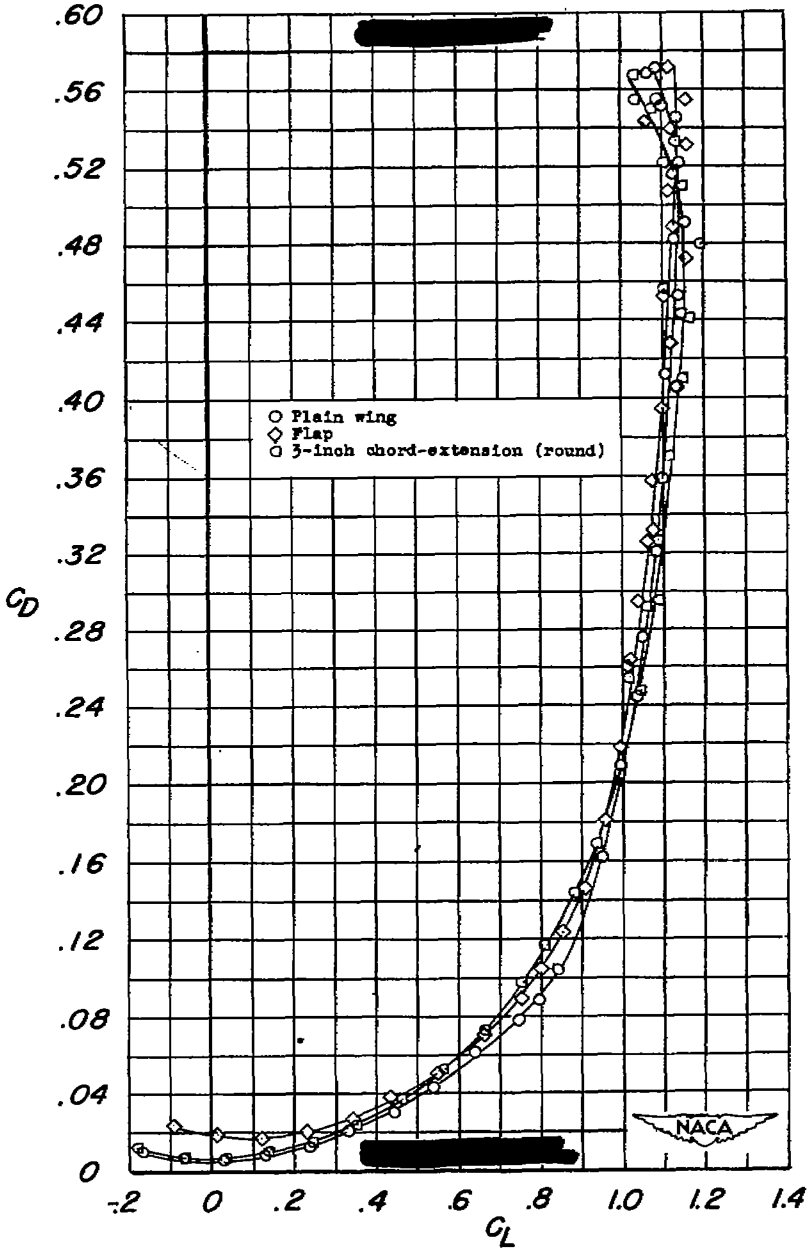

Figure 11.- Concluded.

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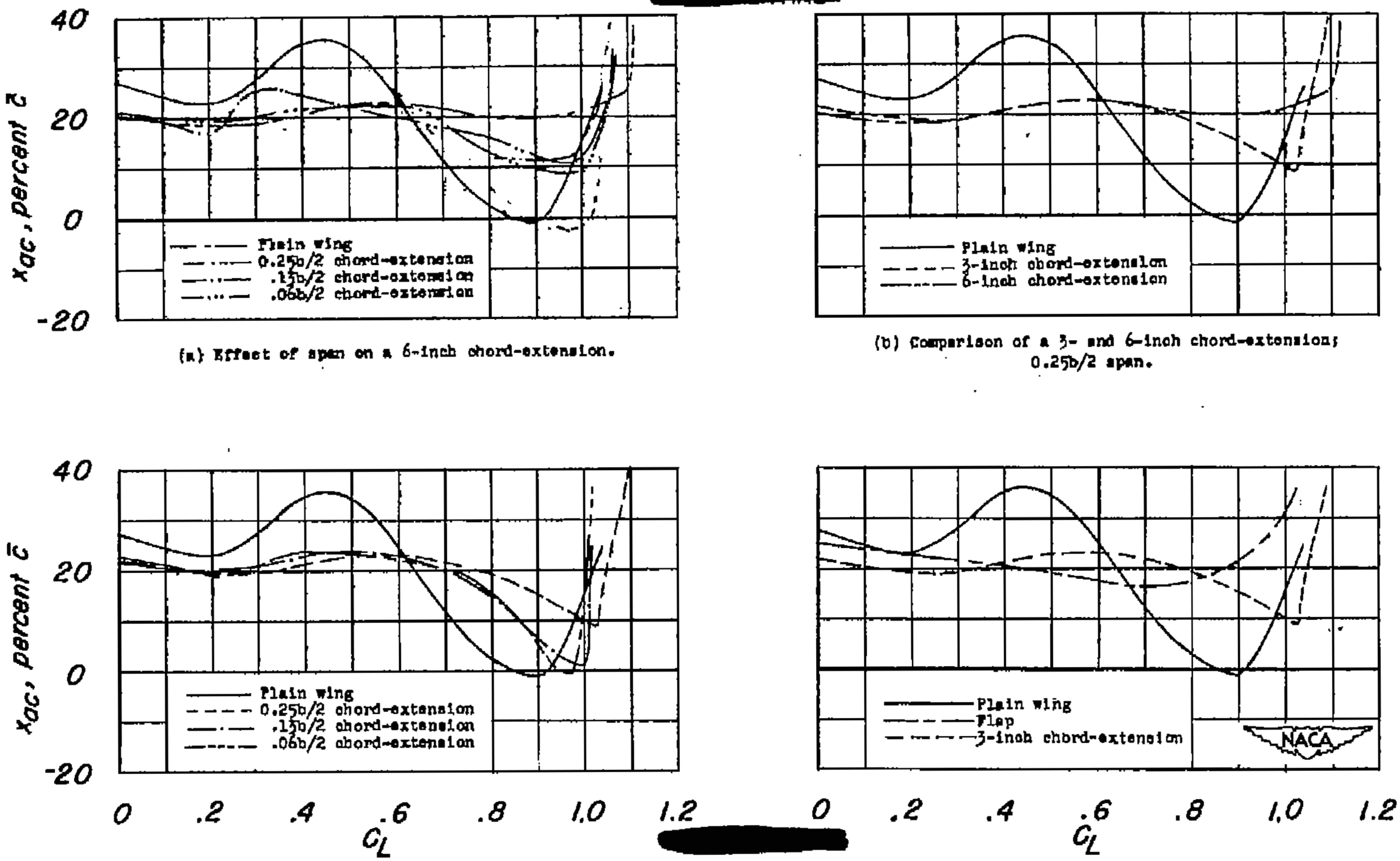

(a) Effect of span on a 6-inch chord-extension.

(b) Comparison of a 3- and 6-inch chord-extension; 0.25b/2 span.

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(c) Effect of span on a 3-inch chord-extension.

(d) Comparison of leading-edge flaps and chord-extensions; 0.25b/2 span.

Figure 12.- Aerodynamic-center variation with lift coefficient of a 52° sweptback circular-arc wing.

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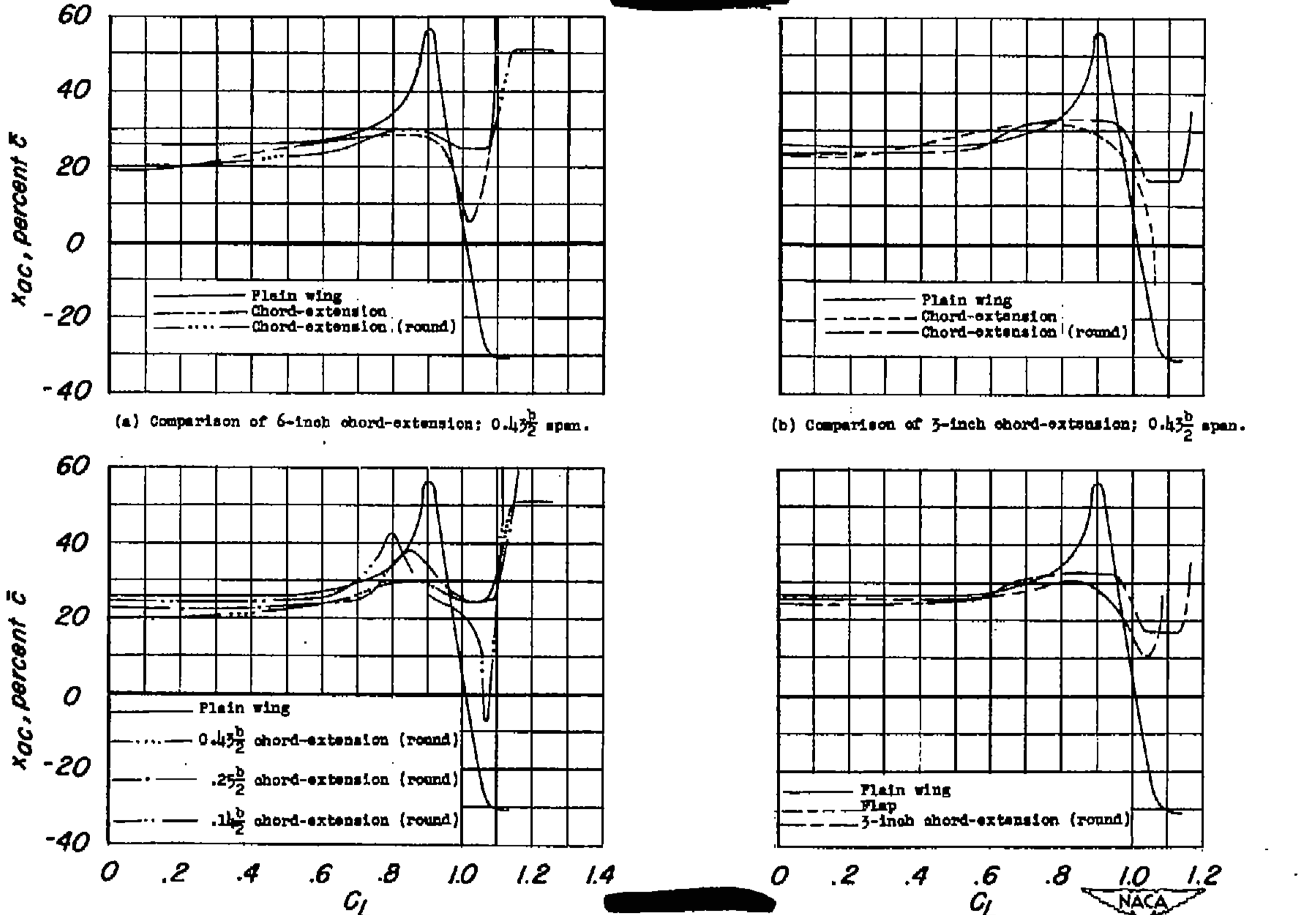

(a) Comparison of 6-inch chord-extension; 0.43$\frac{b}{2}$ span.

(b) Comparison of 3-inch chord-extension; 0.43$\frac{b}{2}$ span.

(c) Effect of span on a 6-inch chord-extension.

(d) Comparison of leading-edge flaps and chord-extension; 0.43$\frac{b}{2}$ span.

[redacted]

Figure 13.- Aerodynamic center variation with lift coefficient of an NACA 64-series 52° sweptback wing.